

Naturally Occurring Arsenic in Sandstone Aquifer Water Wells of Northeastern Wisconsin

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Abstract

The U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 50 µg/L for arsenic was exceeded in 86 of 2125 water supply wells sampled over a broad geographic range in parts of Brown, Outagamie, and Winnebago Counties, Wisconsin. The hydrologic and geochemical properties of the area were examined and the source of arsenic was determined to be natural. Ground water collected from two geologic formations, the St. Peter Sandstone and the overlying Platteville/Galena Dolomite, was found to be the principal source of the elevated arsenic concentrations. These two formations supply a large portion of eastern Wisconsin private wells with their drinking water.

Three wells were found within Outagamie County to have an unusually low pH. Results suggest that the cause of the low pH in these wells is of natural origin induced by the oxidation of iron sulfide minerals. In this reaction iron sulfide minerals are oxidized, forming sulfuric acid causing a low pH and a high concentration of various metals to leach from native rock formations into the water supply.

Based on the data gathered from this study, an arsenic advisory area was designated for both Outagamie and Winnebago Counties. Guidelines were developed for well drillers and owners constructing new wells within the advisory area to reduce the likelihood of arsenic presence in the water supply. Fifteen wells were successfully reconstructed or new wells were constructed based on guidelines developed. These constructions substantially reduced arsenic levels in the well water supplies.

Introduction

Arsenic (As) contamination in water supplies in Winnebago County, Wisconsin, was first identified in two locations in 1987. The Wisconsin Department of Natural Resources (WDNR) initiated a study in 1991 to investigate the occurrence of As in private wells in Outagamie and Winnebago Counties. The study was expanded to include parts of Brown, Marinette, Oconto, and Shawano Counties, Wisconsin, following the results of investigations in Outagamie and Winnebago Counties. The objective of the study was to determine the source and lateral and vertical distribution of As occurring in ground water and geologic formations. The study results were used to develop special well casing and well

Arsenic enters the environment through natural processes or via human activity (Eisler 1988). Natural processes that influence the presence of As are volcanic emissions and weathering of arsenic containing rocks with minerals such as arsenopyrite (FeAsS) (Eisler 1988). Currently, the drinking water standard for total As is 50 µg/L, as established by the Safe Drinking Water Act (SDWA) in 1986.

Geology of Brown, Marinette, Oconto, Outagamie, Shawano, and Winnebago Counties: The Study Area

There are five principal geologic units beneath the glacial overburden in Brown, Marinette, Oconto, Outagamie, Shawano, and Winnebago Counties. The Platteville/Galena Dolomites overlie the Saint Peter Sandstone. Beneath the sandstone are the Prairie du Chien Dolomites and the Cambrian Sandstones. The basement consists of crystalline Precambrian rocks.

The overlying Platteville/Galena Dolomites are composed of sandy-gray to bluish-gray dolomite with fine to medium-grained sandstone near the base (Olcott 1966). The formation generally yields little water to wells (LeRoux 1951). However, in certain locations sufficient quantities of water exist in joints, bedding planes, and fractures to furnish some private wells.

The St. Peter Sandstone is a productive water-yielding unit. It consists of fine to coarse-grained dolomitic sandstone (LeRoux 1957). The St. Peter Sandstone rests on the Prairie du Chien Group filling in low areas but it is absent on the Prairie du Chien highs (Olcott 1966). Water yields from the St. Peter Sandstone are limited by the presence of shale and by the limited thickness of the formation.

The Prairie du Chien is a relatively unproductive water-yielding unit. The Prairie du Chien Group consists of dolomite with thin layers of white sandstone and green shale (Olcott 1966). The upper surface of the Prairie du Chien is highly irregular (Olcott 1966). A limited amount of water is found in fractures, joints, and bedding planes (Olcott 1966).

The Cambrian sequence rests on the irregular and highly eroded surface of the Precambrian rock (Olcott 1966). The Cambrian system is made of fine to coarse-grained sandstone. These sandstones are a major source of ground water, especially for municipal wells. The Precambrian crystalline rocks are composed primarily of granite and, except for fractures, are generally impermeable.

Methodology

Well Water Sample Collection and Analysis Initial water samples were collected by the WDNR following the guidelines set in the WDNR *Groundwater Sampling Procedures Field Manual* and the WDNR *Groundwater Sampling Procedures Guidelines*, both developed by Lindorf, Feld, and Connelly (1987a,b). These were later supplemented by a private well owner sampling program. All samples were collected from a cold water tap situated prior to any in-line treatment device (e.g., a water softener or filter). Samples were collected after flushing the water supply tap for three to five minutes after the pump started running. This procedure identified by Lindorf, Feld, and Connelly (1987a) was used to ensure the water sample represented in situ ground water and not water standing in the pipes. All samples were collected, preserved with 2.5 mL/35% (8N) HNO₃, to a pH of less than 2, and labeled in appropriate 250 mL sample containers supplied by the Wisconsin State Laboratory of Hygiene (WSLH). Samples

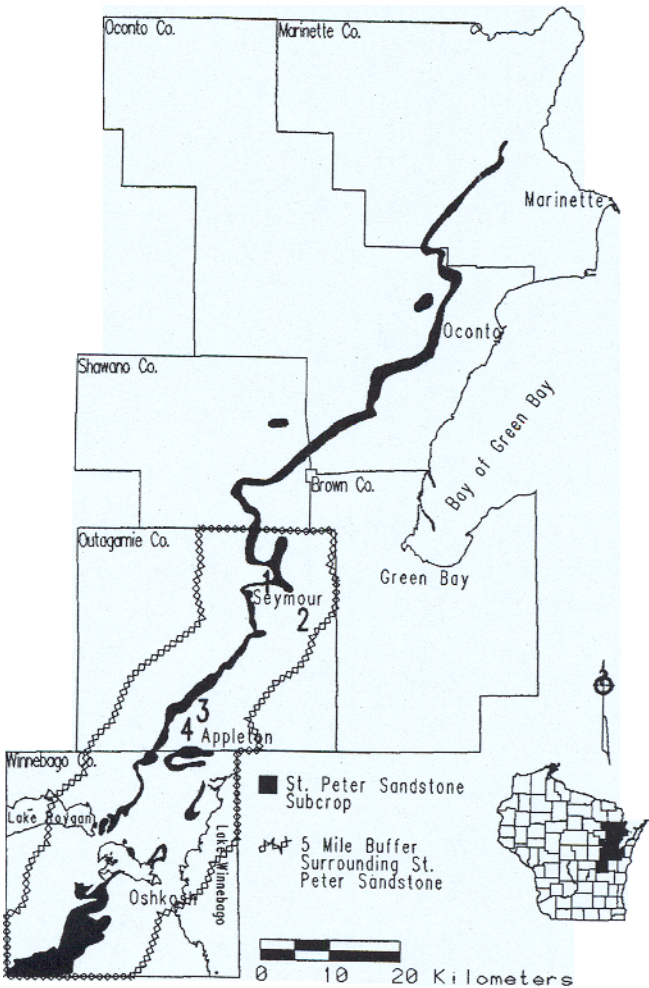


Figure 1. Subcrop of St. Peter Sandstone within portions of Winnebago, Outagamie, Brown, Shawano, Oconto, and Marinette Counties portraying the five mile buffered advisory area.

were analyzed for As by high temperature graphite furnace atomic absorption method, 3113B (American Public Health Association 1989). The methods had either a 2 or a 3 ug/L lower detection limit for As.

All sampled well locations were plotted on 7.5 minute U.S. Geological Survey (USGS) topographic maps or keyed with a global position system (GPS) for digitizing into a geographic information system (GIS). Multiple information layers including land net, railroads, trunk highway network, local roads, hydrology, bedrock geology, glacial geology, potentiometric surface, and all known point and non-point potential ground water contamination sources were created for all of northeast Wisconsin. This information was analyzed with respect to As contamination using PC ARC/Info and ARC View GIS software.

Geophysical Well Investigation Methods - Inflatable Packer Tests

Packer tests were used to isolate and sample specific subsurface water-bearing zones within wells and thus to identify potential subsurface horizons with poor water

Table 1 Arsenic Sampling Results in Brown, Marinette, Oconto, Outagamie, Shawano, and Winnebago Counties, Wisconsin			
County	Total No. Wells Sampled	No. Wells Sampled Exceeding Arsenic SDWA MCL	Percent of Sampled Wells Exceeding Arsenic SDWA MCL
Brown	76	18	23.6
Marinette	33	0	0.0
Oconto	55	0	0.0
Outagamie	1116	45	4.0
Shawano	18	0	0.0
Winnebago	827	23	2.8
All	2125	86	4.0

quality. Two wells, 1 and 4, were chosen for packer testing (Figure 1). Both wells were selected based on their significant depths and the elevated As concentration of their water. See Figures 3 and 4 for wells 1 and 4, respectively, lithology and construction. Furthermore, the family consuming water from well 1 was informed by their physician that they exhibited symptoms associated with chronic As poisoning. Wells 1 and 4 are located about 24 km from each other.

To minimize costs, packer test intervals of 9.1 and 4.6 m (wells 1 and 4, respectively) were selected to best define vertical variations in As concentration throughout the entire well column with the fewest number of packer tests. Each packer interval was pumped for approximately 10 minutes at 37.8 L/min so that a representative water sample could be obtained from each interval.

The integrity of the packer assemblies was monitored using water level indicators throughout the packer tests to verify that the water sampled during the test was actually collected from within the designed packer interval. Samples were collected only from those packer tests with confirmed packer seal integrity or those that showed little fluctuation of water level measurements during pumping. However, due to the type of packer assembly used at well 4, the integrity of the bottom packer seal could not be

monitored. The bottom packer may not have sealed when sampling took place nearest the bottom of the well column. The bottom 6.1 m of the well was filled in with sediment. Sediment and colloidal material clogged the pump and was incorporated into the sample that was analyzed.

For well 1, at packer interval 10, the sample was collected after the pressure tank. The owner required temporary service of water. The pressure tank had a tom bladder. This may have allowed for outside contamination. Also, the water level indicator showed a leaking top packer at interval 10. This may have allowed contaminated water from the upper portion of the well to drain into the area being packed off. All other samples from well 1 were collected directly from the packer assembly, prior to the pressure tank.

The water samples from packer test wells were collected according to WDNR guidelines. Packer test water samples were collected from a brass tap located directly above the packer assembly prior to disposal to a holding tank. Water samples from each packer were tested for field pH and field temperature. The water sample was then filtered using a 0.45 micron filter prior to being sent to the WSLH for analysis of As, cadmium (Cd), copper (Cu), manganese (Mn), and zinc (Zn). These parameters were selected based on the elevated levels found in the original well samples. All samples were collected, preserved with 2.5 mL/ 35% (8N) HNO₃, to a pH less than 2, and labeled in appropriate 250 mL sample containers supplied by the WSLH. Samples were analyzed by high temperature graphite furnace atomic absorption methods and inductively coupled plasma, following procedures 3113B and 3120 (American Public Health Association 1989).

Results and Discussion

Private Well Arsenic Levels The distribution of water well As concentrations in Brown, Marinette, Oconto, and Shawano Counties is markedly different from Outagamie and Winnebago Counties. Arsenic exceedances do not occur in Marinette and Oconto Counties, while limited exceedances occur in part of Brown County. Outagamie and Winnebago Counties exhibit widespread As exceedances over a 110 km area. Winnebago County had 23 of 827 wells sampled that exceeded the SDWA MCL for As, while Outagamie County exhibited 45 of 1116 wells above the MCL (Table 1). Low pHs ranging from 2.5 to 3.8 were documented for three wells in Outagamie County.

Sampling in Brown County was conducted where wells intercept the upper St. Peter Sandstone similar to those in Outagamie and Winnebago Counties. The As problem appears to be a localized problem in parts of Brown County where 18 of 76 wells sampled exceeded the SDWA MCL. Seventeen of these wells exceeding the MCL are located within the same square 2.6 km or township, range, and section. This enclave of impacted wells is surrounded by an area of municipal water service such that additional nearby water sample collection locations are limited. However, one well with As exceeding the MCL is located in the 201, 6S, 17E area.

impacted wells in Brown County. Each of these wells draws water from the upper St. Peter Sandstone. One well with both a field pH as low as 3.1 and As above the MCL is documented in Brown County.

The sample information for Shawano, Oconto, and Marinette Counties indicate this more northern group of counties is much less likely to exhibit As-related drinking water problems. While the sampling conducted in these counties was also along the St. Peter Sandstone sub-crop and conducted similarly, there were no SDWA MCL exceedances or pH problems.

Wells with elevated levels of As were found principally in areas where St. Peter Sandstone is present, based on existing bedrock geology maps (Figure 2). This is where the St. Peter Sandstone is the predominant aquifer supplying private wells. There are, however, some areas

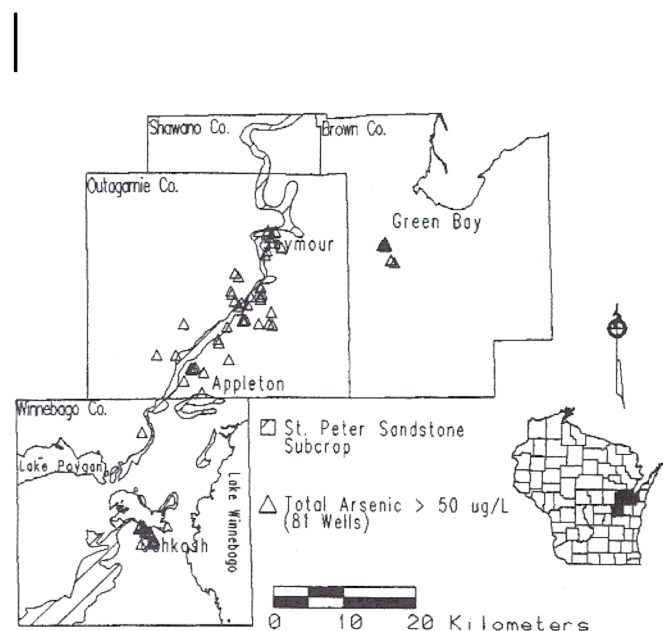


Figure 2. Private wells most impacted by arsenic superimposed on St. Peter Sandstone trend for Brown, Outagamie, and Winnebago Counties.

where wells with elevated As concentrations lie west of the mapped St. Peter Sandstone trend. This is unexpected if the St. Peter Sandstone is the primary source of naturally occurring As in the ground water. The following are three possible explanations for this: (1) the sandstone lenses of the Prairie du Chien or the older underlying sandstone of the Cambrian Formation may also contribute As to well water rather than only the St. Peter Sandstone Formation; (2) some of the St. Peter Sandstone subcrop contacts shown on the bedrock map for this area are inferred. The subcrop was inferred because there was not enough data to map it accurately. These inferred areas correspond to the areas where wells with elevated As concentrations exist to the west of the mapped sub-crop; (3) localized westward shallow ground water flow, impacted by As, may move As downgradient away from the regional divide to where it would not normally be suspected. The regional ground

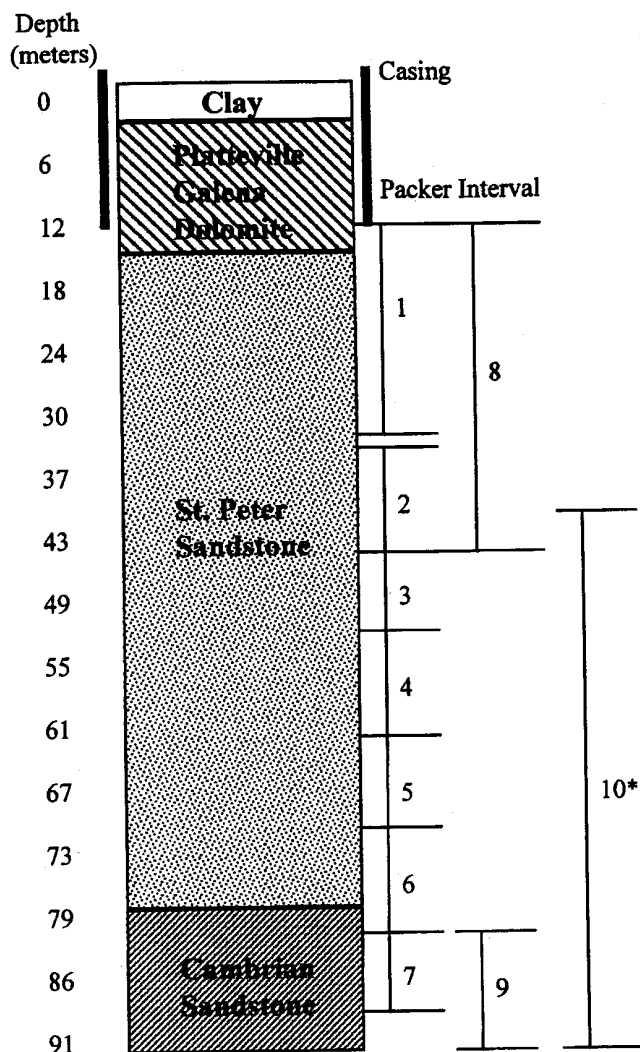
water divide parallels much of the St. Peter Sandstone subcrop expression.

Well 1 - Water Quality

Well 1 was first sampled in 1992, due to the owner complaint of an iron (Fe) problem. The well was sampled for both Fe and As because the well was located near the St. Peter Sandstone trend. Initial test results revealed a high Fe concentration (87 mg/L) and an As concentration of 1200 µg/L, the highest As concentration recorded at that time in a private water supply well in Outagamie County. Two months later a follow-up water sample was collected and analyzed for As, Cd, chloride (Cl), chromium (Cr), conductivity, pH, alkalinity, barium (Ba), calcium (Ca), Cu, Fe, Mn, sodium (Na), Zn, hardness, lead (Pb), nitrate+nitrite-nitrogen, selenium (Se), silver (Ag), sulfate, total solids, field pH, and field temperature. Both the field pH and lab pH indicated normal ranges for ground water from 6 to 8 (standard units). Chloride, Cr, conductivity, alkalinity, Ba, and Ca concentrations were

Packer Interval	Concentration ug/L					
	As	Fe	Cd	Zn	Mn	Cu
1	220	13000	0.6	860	100	<20
2	49	3680	0.3	590	<40	<20
3	9.6	681	0.06	210	<40	<20
4	7.7	823	0.04	210	<40	<20
5	No Water					
6	23	1900	1.2	2900		100
7	24	1700	0.68	510		
8	51.1	4110				
9	24	1800	0.68	470	<40	<20
10*	220	15000	8.2	4900	140	<20

* leaky top packer and sample collected after the pressure tank with torn bladder



KEY

As = Arsenic
Cd = Cadmium
Cu = Copper
Fe = Iron
Mn = Manganese
Zn = Zinc

ug/L = micrograms per liter

Figure 3. Well number 1 packer test results.

were 4.0 mg/L, 8.2 µg/L, 743 umhos/cm, 60 mg/L, <40 Jµg/L, 87 mg/L, respectively. Copper, Na, hardness, Pb, nitrate+nitrite-nitrogen, and total solids concentrations were 390 µg/L, 2.4 mg/L, 350 mg/L, 12 µg/L, <1.00 mg/L, 746 mg/L. Both Se and Ag were not detected. Arsenic and Cd concentrations were 720µ g/L and 53 µg/L, respectively. Arsenic and Cd exceeded the SDWA MCL. Iron, Mn, Zn, and sulfate concentrations were 80 mg/L, 490 µg/L, 20,000 µg/L, and 330 mg/L, respectively. Iron, Mn, Zn, and sulfate concentrations also exceeded the SDWA secondary standards set by the EPA. Furthermore, these results indicated the need to analyze the packer test samples not only for As but for Cd, Fe, Mn, Zn, and sul- fate to further delineate the zones of poor water quality.

Well 1 - Water Quality Packer Test

The results of water samples collected from the packer test intervals at well 1 (Figure 3) show a general decline in As concentrations with depth within the well column. The upper portion of the St. Peter Sandstone exhibits higher As concentrations (34.7 to 43.9 m) than those found in the base of the St. Peter Sandstone (43.9 to 62.2 m) and in the Cambrian Sandstones (71.3 to 91.4 m) found below it. While As concentrations within the borehole water increased in the Cambrian Sandstones, they were below the SDWA and much below the concentration in the upper St. Peter Sandstone.

Iron concentrations follow the same trend as As with higher concentrations in the upper St. Peter Sandstone. The Fe concentration in the well water declines in the lower portion of the St. Peter Sandstone and then rises

somewhat within the Cambrian Sandstones. The Fe concentration in the samples collected from the packer test remains above the SDWA welfare standard (0.3 mg/L) throughout the entire well column. However, the Fe concentrations are significantly reduced from that of the original well, which had an Fe concentration of 80 mg/L.

As a result of this packer test the potable well was deepened to 91.4 m by casing through the upper St. Peter Sandstone to 45.7 m. The resulting As concentration after reconstruction is 12 µg/L, a substantial reduction from the original 1200 µg/L As.

Well 4 - Water Quality

In addition to elevated As and Fe levels of 360 µg/L and 250 mg/L, respectively, well 4 also had an unusually low field pH of 3.8. The water sample was analyzed for Ca, O, conductivity, alkalinity, hardness, Mg, Na, sulfate, and total solids. Arsenic exceeded the SDWA MCL. Iron and sulfate also exceeded the SDWA secondary standards set by the EPA. A caliper log and gamma-ray log were run on well 4 because the well had no subsurface information available below 36.6 m.

Well 4 - Water Quality Packer Test

The results from the well 4 packer test indicated that the As concentrations throughout the entire well column remained above the SDWA MCL of 50 µg/L. The As concentration was highest (>1000 µg/L) at the contact

Packer Interval	Concentration ug/L						pH
	As	Fe	Cd	Zn	Mn	Cu	
1	610	450000	1500	3000	3000	650	2.8
2	450						3.5
3	360						5.2
4	230	160000	270	14000	1000	95	6.1
5	72						6.5
6	51	79000	17	2500	500	41	6.6
7	250						6.1
8	360						5.5
9	400	260000	75	13000	1700	40	5.4
10	370						5.2
11	No Water						
12*	1000	460000	690	35000	1700	5300	5.8

* High sediment content, bottom 6.1 m of well filled in with sediment - invalid data

KEY

As = Arsenic EPAMCL

Cd = Cadmium 50 µg/L As

Cu = Copper 1.0 µg/L Cd

Fe = Iron

Mn = Manganese

Zn = Zinc

WELFARE STANDARDS

0.3 mg/L Fe

50 µg/L Mn

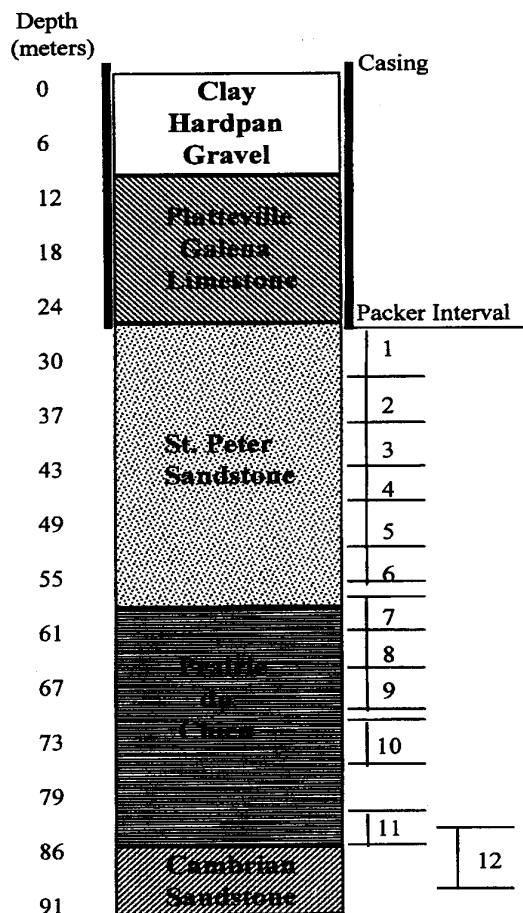
ug/L = micrograms per liter 5000 µg/L Zn

mg/L = milligrams per liter 1300 µg/L Cu

Figure 4. Well number 4 packer test results.

between the Prairie du Chien and the underlying Cambrian Sandstones (83.2 to 87.8 m) (Figure 4). However, this concentration likely resulted from the excessive colloidal sediment found in this zone. The bottom 6.1 m of the well was filled in with sediment. Even though the sample was filtered, the WSLH noted abundant colloidal material which was acidified and analyzed with the sample. Elsewhere throughout the well column, As concentrations were highest in the upper portions of the St. Peter Sandstone (610 µg/L). Arsenic concentrations declined to 51 µg/L at the bottom of the St. Peter Sandstone. The packer test results show the As concentration increasing in the Prairie du Chien dolomite (55.8 to 75.6 m).

Iron concentrations found in all packer test intervals exceeded the SDWA secondary standard for Fe of 0.3 mg/L. Iron concentrations exceeding the standard typically cause aesthetic nuisance problems such as odor and staining. In addition, Cd levels exceeded the SDWA MCL of 10 µg/L in all of the packer intervals analyzed for Cd. Copper concentrations exceeded the SDWA MCL of 1300 g/L in only the lowest interval, which contained large amounts of sediment and colloidal material in the sample. Manganese concentrations remained above the EPA SDWA secondary standard of 50 µg/L in all of the packer intervals analyzed. Zinc concentrations exceeded the SDWA secondary standard of 5000 µg/L in all but



one of the packer intervals tested. The possible presence of drilling grease, thread goop, and galvanized pipe are insufficient to attribute these as the source for a problem of this magnitude and breadth.

An unusually low field pH of 3.8 was recorded for well 4, which provides an explanation as to why excessive amounts of metals were present in the water supply. As pH decreases, the metal ion concentrations in the ground water tend to increase. Low pH values found in the well water may dissolve metallic minerals in the aquifer, increasing the metal ion concentrations.

A replacement well has since been drilled on this property approximately 30.5 m away from the original well and is cased into the Prairie du Chien Dolomite. The replacement well draws water from that dolomite and the underlying Cambrian Sandstone and has tested to be below 2.2 µg/L As, which is a substantial reduction from the original 360 µg/L As. The pH of this new well was not determined.

Two wells in Outagamie County, wells 2 and 3, were found also to have low pH. Well 2, in Oneida Township had a pH of 2.5 and well 3 in Greenville Township had a pH of 3.0. Similarly to well 4, As, Fe, Cd, and Pb (5900, 740,000, 210, 160 µg/L, respectively) were excessively elevated in well water obtained from well 2. Also, through extensive investigation using geophysics, boring, and monitoring well installation, the WDNR has determined that this pH is caused by pyrite oxidation (WDNR 1994). A new well was drilled to replace well 2. This replacement well draws water from the Platteville/Galena Dolomite, has an As value of 4 µg/L compared to 5900 µg/L, and has a pH of 8.22 compared to 2.5.

The original well 3, which was located within 1.6 km of well 4 in Greenville Township, had a recorded pH of 3.0 in 1967. Other nearby wells were sampled and did not exhibit similar low pH values at that time. A new well was drilled to provide potable water with a pH between 6.0 and 9.0. However, a new well construction form was not completed by the driller and further analytical information is not available for the new well.

The well 4 packer test results showed that the pH in the well varied throughout the well column. The pH of the water from the upper portion of the St. Peter Sandstone had substantially lower pH than that of lower portions of the well. It is likely that the acid in the well 4 water is derived from minerals within the St. Peter Sandstone that have oxidized to form sulfuric acid. Lithological analyses have identified arsenic-bearing pyrite and marcasite (FeS₂) to occur within the Platteville/Galena Dolomite and St. Peter Sandstone. Many wells in the study area with elevated As concentrations may not exhibit low pH values due to the mixing and dilution within the entire well column.

Only a few natural reactions are known to cause low pH in ground water. Driscoll (1986) mentions that the acids from mine water are produced from the oxidation of

iron pyrite or other metal sulfide minerals to form sulfuric acid (H₂SO₄).

Oxidation of trace quantities of pyrite and marcasite does contribute to the acidic nature of ground water (Bierens de Haan 1991). Even the simple placement of a marble-sized field sample of this sulfide material in 250 mL of distilled water reduced the pH from 7.0 to 2.0 overnight.

Oxidation of pyrite may also cause elevated levels of As in ground water because As tends to be associated with pyrite and other sulfide minerals. The presence of marcasite and pyrite was documented in well 2, in abundant quantities from a rock core through the upper St. Peter Sandstone (WDNR 1994). Laboratory analysis of

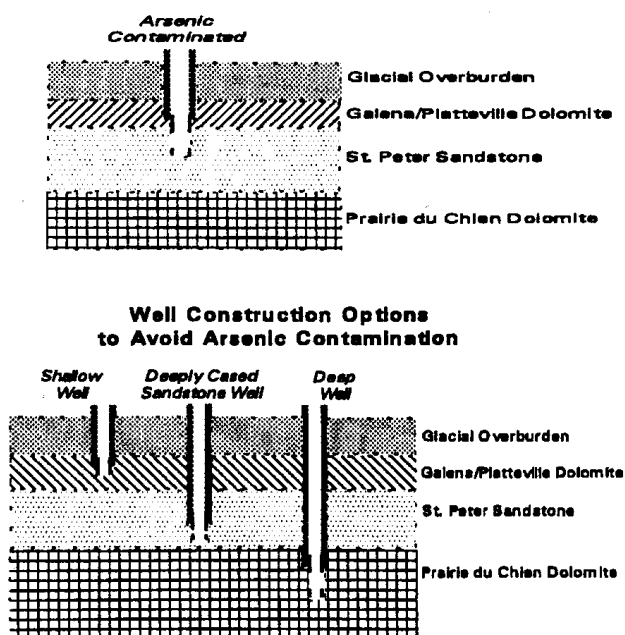


Figure 5. Typical well construction in arsenic contamination.

the sulfide rock material obtained from these well 2 location cores showed that As was present at 150 mg/kg. It is plausible that pyrite and marcasite may also be found in larger lenses or fractures of adjacent rock.

Oxygen may be provided to the iron-rich water flowing from the aquifer at the well/rock interface at the borehole column, or by drilling and pumping (Smith and Tuovinen 1985). Highly acidic environments in aquifers are rare. However, wells with pH values as low as 2.5 can occur as described in wells 2, 3, and 4.

New Well Construction and Well Reconstruction

Packer tests showed a marked increase in As concentration in water from the upper portion of the St. Peter Sandstone. Water from the lower St. Peter Sandstone and the Prairie du Chien units had much lower As concentrations. To minimize As levels in ground

water supplies, the results suggest that one avoid extracting well water from the upper portion of the St. Peter Sandstone aquifer (Figure 5) within the As advisory area (shown in Figure 1).

Arsenic concentrations in private well water have been reduced to below the SDWA MCL by constructing new wells or reconstructing existing wells. A total of 17 wells have been reconstructed or constructed in a new location as part of this study. Two new wells were drilled shallower to draw water only from the Platteville/Galena Dolomite, thus removing the underlying St. Peter Sandstone as the source of water altogether. The other wells were deepened and the casing was extended below the upper St. Peter Sandstone preventing this zone from directly contributing water to the well. Some wells used water exclusively from the Prairie du Chien Dolomite. The other wells obtained water jointly from the Prairie du Chien Dolomite and the underlying Cambrian Sandstone. Fifteen of 17 reconstructions have successfully reduced As concentrations significantly below the SDWA MCL.

Conclusions and Recommendations

This study of As levels in private wells in Brown, Marinette, Oconto, Outagamie, Shawano, and Winnebago Counties has shown that a significant number of wells are affected by high As levels. The present SDWA MCL of 50 µg/L As was exceeded on average of 4% of the total wells tested in Brown, Marinette, Oconto, Outagamie, Shawano, and Winnebago Counties.

This study has provided three lines of evidence that the As found in the ground water in Outagamie, Winnebago, and Brown Counties is of natural origin. First, the pattern of As-contaminated wells is more than 56.3 km long covering an area of approximately 951 km². The aerial extent of the contamination alone clearly suggests that the source of As is not of an anthropogenic source. Also, historical storage of arsenic-based pesticides, such as sodium arsenite used in Wisconsin in the 1930s and 1940s for grasshopper control, did not occur in these areas.

Second, there are a number of natural sources that can contribute to arsenic in ground water. Lithological analyses have identified the presence of pyrite and marcasite in the upper St. Peter Sandstone in wells 2 and 4, as mentioned previously. Pyrite as the principal carrier of As in rocks tends to be associated with mineral deposits of sulfides and sulfo-salts (Eisler 1988). Pyrite exists in layers within the upper St. Peter Sandstone or lower Platteville/Galena Dolomite and thus can contribute As to ground water. Third, ground water extracted during packer tests shows that the highest levels of As occur in the upper St. Peter Sandstone. As previously mentioned, pyrite layers occur within the upper St. Peter Sandstone and can contribute As to ground water.

Computer mapping using GIS was a valuable tool to identify the approximate geographic regions in each county where private wells are affected by naturally occurring As. Nearly all sampled private wells that exceed the SDWA MCL for As are within a 110 km zone

east or west of the mapped St. Peter Sandstone subcrop extending southwest to northeast through Outagamie and Winnebago Counties. Private wells exceeding the SDWA MCL in Brown County are shown to be localized in a specific area. No exceedances of the SDWA MCL for As were found in the wells sampled in Oconto, Marinette, and Shawano Counties.

The aerial distribution of wells within various As concentration ranges was used to develop an As advisory area in Outagamie and Winnebago Counties. Since most private wells within Outagamie and Winnebago Counties range between 30.5 and 48.8 m deep, wells within the advisory area commonly draw water from the St. Peter Sandstone. Those private wells, located outside the 8.0 km boundary from the St. Peter Sandstone, that are drilled deeper than normal may encounter the formation and therefore may contain As, as has happened in Brown County 16 km downdip eastward.

Recommendations were identified through this project for private well users to eliminate or greatly reduce their exposure to As in their drinking water supply. Also, guidelines were developed for well drillers in the area to eliminate and/or greatly reduce As exposure in water wells. The guidelines are as follows:

If As concentration exceeds SDWA MCL: (1) purchase bottled water; (2) install a state-approved water treatment device such as a distillation or reverse osmosis unit to remove As; (3) reconstruct the existing well, or drill a new well that avoids water from the upper St. Peter Sandstone Formation.

If drilling a new well in the advisory area: (5) sample well water for As; (6) construct the well to avoid water from the upper St. Peter Sandstone Formation.

To avoid high As, the St. Peter Sandstone Formation should not be penetrated, especially near the mapped subcrop. If it is necessary to drill through the St. Peter Sandstone to obtain a sufficient volume of water, the upper portions should be cased off to prevent it from supplying water to the well.

Private residences whose well water exceeded the SDWA MCL for As were informed of these measures to reduce the As concentration. Fifteen of 17 wells that were reconstructed due to elevated As did reduce the As concentration substantially. Each of the 17 wells reduced As concentration in the water by removing the upper St. Peter Sandstone unit as the primary water source.

Health studies on individuals that have unknowingly been exposed to elevated As levels from their water supply are ongoing. Few studies currently exist within the United States on the effects of chronic exposure to As. Further examination of the conditions that cause naturally low pH in ground water is occurring. Three wells in this study had an unusually low pH, which appears to be caused by the presence and oxidation of pyrite. This

project identifies the low pH found in these wells is due to natural sources.

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